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perature of the recording layer of the optical disk cools where the data mark is located. The rate at which the data mark location of the recording layer cools determines whether the location cools to an amorphous or a crystalline condition. Typically, the recorded data mark is amorphous and the surrounding area is crystalline.

FIGS. 2a, 2b, 2c show a re-writable optical disk 20 in which data is stored on the optical disk 20 by forming a series of data marks 22 along a track 24 of the optical disk 20. FIG. 20a shows a plan-view of the optical disk 20. FIG. 2b shows an expanded view of the track 24 shown in FIG. 2a. FIG. 2c shows a cross-sectional view of the track 24 shown in FIG. 2b.

In the prior art, placement of data to be written on a recording layer of a re-writable optical disk is typically determined by including synchronization information between fixed-length data fields. A sector is a repeating unit of pre-determined length. FIG. 3a shows a plan-view of a prior art optical disk 30 in which data stored along a servo track 32 is divided into sectors 34. FIG. 3b shows an expanded view of a sector 34 of the optical disk shown in FIG. 3a. The sector 34 includes a header 36, a data field 38 having a predetermined length, and an edit gap 40. FIG. 3c shows an expanded view of the header 36 shown in FIG. 3b. The header 36 includes synchronization information 42 and track address information 44. The synchronization information 42 is also referred to as the sync field. The synchronization information 42 is permanently encoded on the recording layer of the optical disk 30 within the sectors 34. Data written onto the recording layer of the optical disk 30 is synchronized to a write clock. The write clock is synchronized to a clock reference signal which is generated periodically as the synchronization information 42 passes by the optical transducer as the optical disk 30 rotates. The clock reference signal provides position information of the optical transducer with respect to synchronization information 42 on the recording layer of the optical disk 30 when the synchronization information 42 passes by the optical transducer. However, while data within data fields 38 is being written by the optical transducer, the clock reference signal drifts in frequency and phase. That is, when the optical transducer is between points where synchronization information 42 exists, the frequency and phase of the write clock can drift with respect to the synchronization information 42 located within sectors 34. Drift of the write clock with respect to the synchronization information 42 can be caused by disk rotation speed variations, servo track eccentricity and the cumulative effect of other variations in an optical disk recorder such as clock frequency drift. In general, the greater the distance between sync fields, the greater the drift of the write clock.

The edit gap 40 shown in FIG. 3b is included within the sector 34. A data field which includes a fixed number of data bits is typically written to the sector 34 of the recording layer of the optical disk 30. The edit gap 40 accommodates variations in the placement of the last data bit of a data field which is written to the sector 34. That is, although all data fields normally contain the same number of data bits, the edit gap 40 allows the placement of the last data bit of a data field to be different each time the data field is re-written. Therefore, placement of bits written to the recording layer is not required to be as precise as the placement would be required to be if the edit gap 40 did not exist. Edit gap are needed to accommodate drift of the write clock in prior art re-writable optical disks.

Presently existing DVD read only memory (ROM) formats do not include physical sectoring of data stored on the

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servo tracks. A clock reference structure is formed along the servo tracks. The clock reference structure permits data to be written to the recording layer in data fields of indeterminate length. The clock reference structure comprises a reference spatial frequency which is greater than a predetermined spatial frequency. An extension of this embodiment includes the predetermined spatial frequency being greater than the maximum spatial frequency detectable by a standard DVD-ROM reader.

Another embodiment of the invention includes an optical disk recorder in which an optical disk is rotatably mounted on the recorder. The optical disk includes a recording layer containing servo tracks. An optical transducer radially follows a servo track as the optical disk rotates. A clock reference structure pre-exists along the servo tracks and provides data fields of indeterminate length. The clock reference structure causes the optical transducer to produce a clock reference signal as the optical disk rotates. The optical disk recorder further includes a means for recording data marks on the recording layer of the optical disk. The data marks are recorded so that a standard DVD-ROM reader can read the data marks but the optical disk is constructed so that the reader cannot detect the clock reference structure. A write clock determines the physical placement of data marks written on the recording layer of the optical disk. The write clock is phase locked to the clock reference signal.

Another embodiment of the invention includes an optical disk recorder for receiving an optical disk. The optical disk is rotatably mountable on the recorder. The optical disk includes a recording layer having servo tracks and a clock reference structure having a spatial frequency which is too high to be detected by a standard DVD-ROM reader. The clock reference structure is formed along the servo tracks and provides data fields of indeterminate length. The optical disk recorder includes an optical transducer which is optically coupled to the recording layer of the optical disk. The optical transducer follows the servo tracks of the optical disk as the optical disk rotates. The clock reference structure formed along the servo tracks of the optical disk causes the optical transducer further includes a means for writing data marks on the recording layer of the optical disk. A write clock determines the physical placement of data marks written on the recording layer of the optical disk. The write clock is phase locked to the clock reference signal.

Other aspects and advantages of the present invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1a shows a plan-view of a prior art ROM optical disk.

FIG. 1b shows an expanded view of a track shown in FIG. 1a.

FIG. 1c shows a cross-sectional view of the track shown in FIG. 1b.

FIG. 2a shows a plan-view of a prior art re-writable optical disk.

FIG. 2b shows an expanded view of a track shown in FIG. 2a.

FIG. 2c shows a cross-sectional view of the track shown in FIG. 2b.

FIG. 3a shows a plan-view of a prior art optical disk 30 in which data stored along a servo track 32 is divided into sectors 34.

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FIG. 21 shows an embodiment of the invention having a second optical transducer for reading data.

FIG. 22 shows an embodiment of the invention having another configuration of a second optical transducer which shares a combination objective lens with a first optical transducer.

# DETAILED DESCRIPTION

As shown in the drawings for purposes of illustration, the invention is embodied in an optical disk structure and optical disk recorder which enables data to be written or re-written onto the recording layer of the optical disk. The data can be written or re-written with sub-bit accuracy without requiring the unwritten optical disk to be divided into physical sectors. Furthermore, synchronization fields and edit gaps are not required on an optical disk on which data is to be written. The optical disk recorder includes an optical transducer which can resolve and detect a high spatial frequency clock reference structure located on the optical disk. Standard DVD-ROM disk readers are not able to resolve and detect the clock reference structure. Therefore, the optical disk structure and optical disk recorder of this invention allow production of re-writable optical disks which can be read by standard DVD-ROM disk readers. Additionally, the optical disk recorder can read optical disks.

A clock reference structure is permanently formed along servo tracks of the optical disk. An optical transducer is coupled to the clock reference structure and generates a clock reference signal simultaneously with writing new data onto the recording layer of the optical disk. The data is written as data marks along the servo tracks. Each of the data marks includes a first and a second edge. During recording, the edges of the data marks are formed in synchronization with a write clock. Therefore, each time the edge of a data mark is formed, the write clock had completed the same fraction of a cycle. The write clock is phase-locked to the clock reference signal. Therefore, the edges of the data marks are formed in synchronization with the clock reference signal with sub-bit accuracy. Therefore, the edges of the data marks are accurately aligned with the clock reference structure. The edge of the data mark is only recorded when required by the data written and the data encoding scheme. Many cycles of the clock reference structure will not have a corresponding data mark edge.

FIGS 4a, 4b, 4c illustrate a comparison of the fields of information along the tracks of two prior art optical disks, and the data fields of the present invention. FIG. 4a shows a prior art sector which includes a sync field 42, a servo field 46, an address field 44, a data field 38 and an edit gap 40. FIG. 4b shows a prior art sector which includes a sync field 42, an address field 44, a data field 38 and an edit gap 40. FIG. 4c shows a data field 50 of the invention. The present invention does not require a sync field, an address field, a servo field or an edit gap. Furthermore, the data field 50 of the invention is arbitrary in length. The clock reference structure provides synchronization information which is precise enough to allow elimination of edit gaps. The track address information is included within the clock reference structure.

As shown in FIG. 4c, the data fields of the invention are indeterminate in length. A data field of indeterminate length is a data field in which the data field length and corresponding data capacity are not determined by any permanent structure formed on the optical disk. Therefore, the lengths of data blocks can be determined solely by the requirements of the format and the code used to record the data. Many data formats, including the DVD format, establish uniform data field lengths and include addresses and synchronization

Another embodiment of the invention includes the data marks 58 being formed on the recording layer by heating the

The edges of the grooves can be formed to oscillate substantially 180 degrees out-of-phase by modulating the power of the laser beam while exposing the photoresist in the mastering process. Numerous practical methods exist for modulating the power of a laser beam at a high frequency. Some lasers can be modulated directly by controlling a current or voltage source connected to the laser. Otherwise,



In FIG. 9a, edges of data marks 19 are spatially aligned with the clock reference structure and are therefore temporally aligned with the clock reference signal. Data marks 19 which pre-exist on the disk do not affect the process of generating the write clock and will be over-written with new data.



The ability of an optical system to resolve fine structures like the clock reference structure of the invention is described by the modulation transfer function (MTF) of the optical system. Using methods such as Fourier transforms, the spatial distribution of light leaving an object can be represented as a spatial frequency distribution, in which each spatial frequency component has a particular amplitude and phase. A similar approach is commonly used to represent an electrical signal in terms of the component temporal frequencies of the electrical signal. An optical system such as a lens, acts as an optical filter which selectively attenuates each spatial frequency component in an image formed by the lens. For each spatial frequency component, the lens has a transfer factor which determines the ratio of image modulation (lens output) to object modulation (lens input). The MTF of the lens specifies the transfer factor as a function of spatial frequency.

An aberration-free lens such as the objective lens in the optical transducer of an optical disk recorder or reader, has an MTF which is well known in the art of optics as being the appropriately scaled autocorrelation of the pupil function. FIG. 11 is a graph of the MTF for two aberration-free optical transducers having uniformly filled circular pupils. The functional form of the MTF is similar for all aberration-free optical transducers. However, the spatial frequency at which the MTF goes to zero, known as the cutoff frequency, depends on the numerical aperture (NA) of the objective lens and the wavelength ( $\lambda$ ) of the light forming the image. The cutoff frequency is determined by  $2 \cdot \text{NA} / \lambda$ , and is the highest spatial frequency that can be detected by the transducer. Any spatial frequency component higher than the cutoff frequency will not exist in the output of the optical transducer. In an optical disk reader or recorder, the cutoff frequency is determined by the wavelength of the light source and the numerical aperture of the objective lens used to focus a light beam onto the recording layer of an optical disk. Curve 116 of FIG. 11 illustrates the MTF of an optical transducer having a numerical aperture of 0.60 and an operating wavelength of 650 nm. The cutoff frequency for this optical transducer is 1.85 cycles/ $\mu\text{m}$ .

Manufacturers of optical disks and optical readers develop and agree to optical data storage industry standards. These standards ensure that any optical disk can be read by any optical disk reader if the optical disk and the reader conform to the same industry standards. DVD is an example of an industry standard. The specifications for DVD define numerous parameters of both DVD disks and DVD readers. The specifications include certain parameters of the optical transducer in the optical disk reader. These parameters include the wavelength (650 nm) and the numerical aperture (0.60) of the light beam focused on the optical disk. Curve 116 represents the MTF for the optical transducer of an industry standard DVD optical disk reader. As illustrated by curve 116, and as calculated above, the cutoff frequency for an industry standard DVD reader is 1.85 cycles/ $\mu\text{m}$ .

The DVD standard only applies to read-only-memory (ROM). The DVD standard does not specify the design and manufacture of re-writable optical disks that can be read by industry standard DVD optical disk readers. There is a 65 market demand for re-writable DVD disks and for optical disk recorders for writing data to the re-writable DVD disks.

An object of this invention is to provide a continuous and permanent clock reference structure for use in recording re-writable DVD disks, wherein the clock reference structure can not be detected by industry standard DVD readers.

5 Curve 118 of FIG. 11 represents the MTF of an optical transducer of an optical disk recorder constructed according to the principles of the present invention. As illustrated by curve 118, the MTF of this optical transducer is greater at all spatial frequencies than the MTF of the optical transducer of  
10 an industry DVD optical disk reader as illustrated by curve 116. In addition, cutoff frequency 119 for the optical disk recorder (2.46 cycles/um) is greater than the cutoff frequency 117 of an industry standard DVD reader (1.85 cycles/um).

15 Curve 118 represents the MTF of an optical transducer having a numerical aperture of 0.8 and a light beam wavelength of 650 nm. However, curve 118 can alternatively represent the MTF of an optical transducer in which the numerical aperture is 0.6 and the light beam wavelength is  
20 488 nm. In either of these example cases, the cutoff frequency 119 is 2.46 cycles/um and the shape of the MTF curve is as represented by the curve 118.

FIG. 11 also shows the clock reference structure spatial frequency 121 of 1.875 cycles/um. The spatial frequency of  
25 the clock reference structure is too high for a DVD reader to detect. That is, the spatial frequency of the clock reference structure is higher than the 1.85 cycles/um cutoff frequency of an industry standard DVD reader. However, the MTF of the optical transducer of the disk recorder constructed  
30 according to the principles of the present invention has a cutoff frequency 119 which is greater than the spatial frequency of the clock reference structure. Therefore, the disk recorder can detect the clock reference structure and the DVD reader cannot. The numerical values presented here  
35 are by way of example. The principles are the same for optical disk readers which have a higher or a lower cutoff frequency. FIG. 12 shows an embodiment of the electronic control circuitry 83 which synchronizes the clock reference signal with the write clock. The write signal which is  
40 synchronized with the write clock controls when the optical transducer 82 writes first and second transition edges of the data marks to the surface of the optical disk 80. Generally, the write clock functions at a frequency which is greater than the frequency of the clock reference signal recovered from  
45 the optical disk 80 by the optical transducer 82.

The write clock is synchronized to the recovered clock reference signal using a harmonic locking phase-locked loop shown in FIG. 12, and described in detail in F. M. Gardner (pp 201-204, Phaselock Techniques, John Wiley & Sons,  
50 second edition, New York, N.Y., 1979).

The clock reference signal having a clock reference frequency (fr) is coupled to the phase-locked loop through a zero crossing detector 1012. The zero crossing detector 1012 converts the clock reference signal into a square wave. The  
55 square wave is coupled to a phase detector 1014. The write clock is generated at a frequency ( $N \cdot fr$ ) by a voltage controlled oscillator (VCO) 1016. An output signal (write clock) of the VCO 1016 is frequency divided by a frequency divider 1018. The output of the frequency divider 1018 is  
60 coupled to the phase detector 1014. The phase detector 1014 generates a phase detect signal in which the amplitude of the detect signal is proportional to the phase difference between the frequency-divided VCO signal and the square clock reference signal. Various embodiments of the phase detector  
65 exist, some of which include charge pump circuitry. The phase detect signal is amplified and filtered by a loop amplifier/filter 1020. The output of the amplifier/filter 1020

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The harmonic locking phase-locked loop accomplishes two functions. The first function is to generate a write clock which is at N times the frequency ( $f_r$ ) of the detected clock reference signal. The second function is to minimize the phase difference between the clock reference signal and the divided VCO signal.

Essentially, there is a practical limitation to the size of  $N$  due to the amplification of jitter and noise in the loop. For this reason, when write clock frequency greater than the clock reference frequency is required, it is most advantageous to maximize the clock reference frequency. Therefore,  $N$  is minimized, which minimizes the jitter.

The data signal and the clock reference signal are both coupled to the optical transducer in both optical disk readers and optical disk writers. Therefore, the data signal and the clock reference signal must be separated. To understand the process of separating the data signal from the clock reference signal, it is important to realize that as the optical disk rotationally passes under the optical transducer at a particular velocity, spatial frequencies of structures on the recording layer of the optical disk are translated into temporal frequencies. For a given spatial frequency ( $v$ ) on the optical disk and a given linear velocity ( $v$ ) of the disk passing under the transducer, there is a specified temporal frequency ( $f$ ) such that  $f$  is equal to  $v \cdot v$ . Therefore, the spatial frequency relationship between the data marks and the clock reference structure is preserved as a temporal frequency relationship between the data signal and the clock reference signal.

In prior art clock generation schemes that use synchronization fields in sector headers, the separation of the data signal and the clock signal is realized by spatially alternating the data and clock signals. The separation is accomplished by only re-synchronizing the write clock during the sector headers and running the write clock open loop while the optical transducer is coupled to data fields of the optical

5 spatial multiplexing as previously described, can not be used to obtain a clock reference structure which is coincident with the data structure. Rather, it is necessary that the clock reference signal be separable from the data signal while data is being read or written. Generally, there are three  
10 optical storage configurations available for accomplishing the required separation of the clock reference signal and the data signal.

A second configuration includes the clock reference structure having a spatial frequency which is greater than the spatial frequency of the data. FIG. 14 shows the frequency spectrum of the second configuration. The data is stored on the optical disk so that the data spatial frequency spectrum 1210 is lower than the clock reference structure spatial frequency 1212. For this configuration, an optical reader like a DVD-ROM optical reader, can not detect the spatial frequency of the clock reference structure. That is, the optical resolution of the optical disk writer is greater than the optical resolution of the optical disk reader. The optical disk writer can acquire and isolate the clock reference signal while excluding the data signal due to pre-existing data using well known signal processing techniques.

50 The first configuration constrains the coding of data stored on the optical disk to an extent that this configuration can not be used for writing data to optical disks which are to be read by a DVD-ROM reader.

The optical disk of the present invention includes construction for producing a data signal with a high signal-to-noise ratio (SNR) when read by an optical disk reader. A clock reference signal is an unwanted source of noise if it appears within the data signal of the reader. The optical and electronic specifications of the optical transducer of a standard DVD optical disk reader are defined by a DVD format

In an optical disk recorder, significant additional rejection of the data signal is obtained by detecting the clock reference signal split detection (sometimes called tangential push-pull detection), an optical detection method well known in the art. In FIG. 10, an optical detector 114 is located substantially at a pupil of the optical transducer (an optical location sometimes referred to as "in the far field of the disk"). The lens 194 forms a pupil at detector 114 by forming an image of aperture stop 99 on detector 114. FIG. 17 shows an enlarged plan view of optical detector 114. The circular perimeter 31 shows the outer boundary of the area of detector 114 that is illuminated by beam 106 of FIG. 10. Line 29 indicates the tangential direction relative to the disk (servo tracks are parallel to the tangential direction). The detector 114 is symmetrically divided into four detection areas called quadrants. Each quadrant produces an electrical output signal which is substantially proportional to the optical power incident on that quadrant, as is well known in the art. As shown in FIG. 17, detector quadrants 21, 23, 25 and 27 produce electrical output signals A, B, C, and D,

5 readout has been extensively studied, and the characteristics of signals produced using split detection are well known for a variety of structures on the recording layer.

data marks primarily affect the amplitude of the reflected light but not its phase. (Note that the name "phase change" applies to the crystalline or amorphous phase of the recording layer, not whether the recorded marks affect the amplitude or phase of the incident light.) The clock pits which constitute the clock reference structure produce a well-modulated clock reference signal when detected using split detection in the transducer of the optical disk recorder. For best SNR of the clock reference signal, the preferred round trip optical depth for the pits is  $\lambda/4$ , where  $\lambda$  is the wavelength of the light used in the optical transducer of the optical disk recorder. The optical depth of structures on the recording layer of an optical disk is defined as physical depth multiplied by the refractive index of the disk substrate material in contact with the recording layer.

25 optical transducer which produces a clock reference signal using split detection. Split detection causes a reduction in MTF at low spatial frequencies, but does not reduce the cutoff frequency or the MTF of the optical transducer of the recorder at the clock reference structure spatial frequency  
30 121. Split detection therefore provides a means for producing a well-modulated high-resolution clock reference signal in the recorder while writing or re-writing data on an optical disk of the invention.

In a second embodiment clock reference structure, as depicted in FIG. 19, servo tracks comprise grooves 3 in the recording layer and the clock reference structure comprises edges of grooves 5, 7 which oscillate substantially 180 degrees out of phase. For best clock reference signal SNR, the preferred round-trip optical depth of the grooves is  $\lambda/4$  where  $\lambda$  is the wavelength of the light used in the optical transducer of the recorder. Data marks 19 are recorded along servo tracks.

tion is a method well known in the art which forms a signal by summing the four quadrant signals produced by a quadrant detector similar to the optical detector 114 of FIG. 17. The CAP detection signal is the  $(A+B+C+D)$  where A, B, C, D represent the signals from the detector quadrants. Alternatively, a detector with a single detection area large enough to capture the entire beam diameter is equivalent and may be used. CAP detection is well known in the art to have low sensitivity to structures on the recording layer having a round trip optical depth of  $\lambda/4$  where  $\lambda$  is the wavelength of the light used in the optical transducer of the reader. This signal rejection characteristic of CAP detection permits the use of clock reference structures such as those shown in FIG. 19 with spatial frequencies below the cutoff frequency of the optical transducer of a standard optical disk reader.

60 In a preferred configuration, however, the spatial frequency of the clock reference structure exceeds the cutoff frequency of the optical transducer of a standard optical disk reader. In this case, the clock reference signal will be entirely eliminated from the data signal produced by the standard  
65 optical disk reader.

In an optical disk recorder, constructed to record data on disks having a reference structure comprising groove edges



that oscillate substantially 180 degrees out of phase, the preferred method for detecting the clock reference signal is split detection, as previously described herein. As previously described, split detection produces substantially no signal from data marks, such as phase change marks, which primarily affect the amplitude of the reflected light. As previously noted, and as shown by curve 123 in FIG. 18, split detection maintains the full MTF and cutoff frequency of the optical transducer of the recorder at the clock reference signal spatial frequency 121, enabling a well-modulated clock reference signal to be produced.

In a third embodiment clock reference structure, as depicted in FIG. 20, servo tracks comprise grooves 3 in the recording layer, the clock reference structure comprising edges 5, 7 of grooves which oscillate in phase. The preferred round-trip optical depth of the grooves is  $\lambda/4$ . Data marks 19 are recorded along servo tracks. As previously discussed, a standard optical disk reader uses central aperture (CAP) detection for generating a data signal. It is well known in the art of optical data storage that CAP detection substantially does not detect a signal produced by groove edges that oscillate in phase. It is also well known that CAP detection has very low sensitivity to structures having a round trip optical depth  $\lambda/4$ . These two modes of signal rejection work together to enable the spatial frequency of the clock reference structure to be below the cutoff frequency of the optical transducer of a standard DVD reader without producing unacceptable levels of noise in a data signal produced by the reader.

In an optical disk recorder, constructed to record data on disks having a reference structure comprising groove edges that oscillate in phase, the preferred method for detecting the clock reference signal is radial push-pull detection, an optical method well known in the art of optical data storage. Radial push-pull detection forms a signal according to the formula  $((A-B)-(C-D))$ , which is sometimes normalized by dividing by  $(A+B+C+D)$ . As previously discussed, A, B, C and D are electrical outputs from quadrants 21, 23, 25 and 27 of detector 114 in FIG. 17. Radial push-pull detection produces substantially no signal from data marks. Data marks are not detected, first because they primarily affect the amplitude of the reflected light, and secondly because they are nominally symmetric about the center of the track. As is well known in the art, radial push-pull detection is sensitive to structures which affect the phase of the reflected light and which are asymmetric about track center. Radial push-pull detection produces a well-modulated signal from groove edges which oscillate in phase, especially when the round trip optical depth of the groove is  $\lambda/4$ . Radial push-pull detection produces a well-modulated signal from groove edges which oscillate in phase, especially when the round trip optical depth of the groove is  $\lambda/4$ . Radial push-pull detection provides sufficient rejection of the undesired data signal to permit recovery of a clock reference signal having frequency within the frequency range of the data. It is desirable to provide the ability to use a clock reference structure with a spatial frequency below the cutoff frequency of a standard optical disk reader because the radial push-pull signal detection method reduces the cutoff frequency of the recorder's optical transducer when recovering a clock reference signal. Curve 125 of FIG. 18 illustrates the MTF for an optical transducer in an optical disk recorder during detection of a clock reference structure using radial push pull detection. The cutoff frequency ( $f_c$ ) of the optical transducer of the optical disk recorder for purposes of detecting a clock reference structure is reduced from a value of  $2NA/\lambda$  to a value of:

$$f_c = \sqrt{(2NA/\lambda)^2 - (1/P^2)}$$

5 Where the track pitch P is the radial distance between track centers. The MTF curves of FIG. 18 have been derived for the same optical transducers that are represented by MTF curves 116 and 118 of FIG. 11. Curves 116 and 118 are shown again as dotted curves in FIG. 18. In FIG. 18, the  
10 MTF of the optical transducer in an optical disk recorder is represented by curve 118. When a clock reference signal is detected using radial push pull detection, the MTF of the optical transducer is reduced. Curve 125 shows the reduced MTF. The cutoff frequency has also been reduced, from 2.46  
15 cycles/um for curve 118 to 2.06 cycles/um for curve 125. This MTF decline associated with radial push pull detection significantly reduces the modulation of a clock reference signal having a spatial frequency above the cutoff frequency of a standard optical disk reader. For this reason, the  
20 preferred configuration of this embodiment uses a clock reference structure having a spatial frequency below the cutoff frequency of a standard optical disk reader. Note that the MTF reduction illustrated with reference to FIG. 18 applies only to the detection of the clock reference structure  
25 and does not affect the resolution of the optical transducer for the purpose of recording data.

Note that the radial push pull signal contains tracking error information at frequencies substantially below the clock reference signal frequency and may also be used 30 generate a tracking error signal for use by a tracking positioner.

The invention can include other clock reference structures such as a clock reference structure which consists of a groove having a single edge which oscillates. The three 35 clock reference structures described here are by way of example.

FIG. 21 shows another embodiment of the optical disk recorder of the invention which includes a second optical transducer 182 for reading data stored on an optical disk 80. The optical disk recorder 81 has a first optical transducer 82 and a second optical transducer 182 which are optically coupled to the recording layer of the optical disk 80. The first optical transducer 82 is used for recording data and operates as previously described with reference to FIG. 10. The second optical transducer 182 follows a servo track as the optical disk 80 rotates. The data marks cause the second optical transducer 182 to produce a data signal as the optical disk 80 rotates. The second optical transducer 182 includes several optical devices and has many similarities with optical transducer 82. A laser 190 emits a linearly polarized beam of light 192 which is collimated by a collimator lens 194. The light beam 192 passes through a polarization beam splitter 196. The light beam 192 is converted from linear polarization to circular polarization by a quarter wave retardation plate 198. The light beam 192 is focused by an objective lens 200 onto the recording layer of the optical disk 80 containing recorded data marks. A portion of the light beam 192 is reflected by the optical disk 80 and returns through the objective lens 200 and the quarter wave plate 198. Upon passing back through the quarter wave retardation plate 198, the light beam 192 is again linearly polarized. However the polarization direction of the light beam 192 is rotated 90 degrees relative to its initial orientation. Therefore, the polarization beam splitter 196 reflects substantially all of light beam 192 towards beam splitter 202. The beam splitter 202 splits the beam 192 into a first light beam 204 and a second light beam 206. The first light beam

204 is collected by a first light beam 204 and a second light beam 206. The first light beam 204 is collected by a first lens 208 onto a first detector 210 which is arranged to produce a focus-error signal. The second light beam 206 is collected by a second lens 212 onto a second detector 214 which is arranged to produce a data signal. The second detector 214 also produces a tracking-error signal used by a tracking positioner. Detectors 210 and 214 generally include multiple detection areas and produce multiple detection signals as is well known in the art. Many alternative arrangements of the optical components and detectors are possible, including arrangements which combine or eliminate optical components shown in FIG. 21.

FIG. 22 illustrates another embodiment of the optical disk recorder of the invention. This embodiment includes another configuration of a second optical transducer 282 for reading data stored on an optical disk 80 and uses the same objective lens 100 as optical transducer 82 which is used for recording data. The shared objective lens is referred to as a combination objective lens 100. FIG. 22 shows the optical disk recorder 81 in which the second optical transducer 282 is optically coupled to data marks on the recording layer of optical disk 80. The second optical transducer follows a servo track as the optical disk rotates. The data marks cause the second optical transducer to produce a data signal as the optical disk rotates. As illustrated in FIG. 22, the second optical transducer 282 includes several optical devices and has many similarities with optical transducer 82. A laser 290 emits a linearly polarized beam of light 292 which is collimated by a collimator lens 294. The light beam 292 passes through a polarization beam splitter 296. The light beam 292 is converted from linear polarization to circular polarization by a quarter wave retardation plate 298. The light beam 292 then passes through an aperture stop 99 and is focused by an objective lens 100 onto the recording layer of the optical disk 80 containing recorded data marks. A portion of the light beam 292 is reflected by the optical disk 80 and returns through the objective lens 100 and the quarter wave retardation plate 298. Upon passing back through the quarter wave retardation plate 298, the light beam 292 is again linearly polarized. However the polarization direction of the light beam 292 is rotated 90 degrees relative to its initial orientation. Therefore, the polarization beam splitter 296 reflects substantially all of light beam 292 towards beam splitter 302. The beam splitter 302 splits the beam 292 into a first light beam 304 and a second light beam 306. The first light beam 304 is collected by a first lens 308 onto a first detector 310 which is arranged to produce a focus-error signal. The second light beam 306 is collected by a second lens 312 onto a second detector 314 which is arranged to produce a tracking-error signal used by the tracking positioner, and a data signal containing information encoded in data marks on optical disk 80. Detectors 310 and 314 generally include multiple detection areas and produce multiple detection signals as is well known in the art. Many alternative arrangements of the optical components and detectors are possible, including arrangements which combine or eliminate optical components shown in FIG. 22. The laser 290 emits light at a longer wavelength than the laser 90. The beam splitter 296 is a wavelength sensitive beam splitter (sometimes called a dichroic beam splitter) which transmits light of a first wavelength and reflects light of a second wavelength. The shorter wavelength laser 90 of optical transducer 82 provides a smaller focused spot of light and a correspondingly higher MTF and cutoff frequency for recording data marks and producing a clock reference signal. The longer wavelength laser 292 of second optical transducer 282 provides a

FOOTNOTES: 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438, 439, 440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 451, 452, 453, 454, 455, 456, 457, 458, 459, 460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 497, 498, 499, 500, 501, 502, 503, 504, 505, 506, 507, 508, 509, 510, 511, 512, 513, 514, 515, 516, 517, 518, 519, 520, 521, 522, 523, 524, 525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 559, 560, 561, 562, 563, 564, 565, 566, 567, 568, 569, 570, 571, 572, 573, 574, 575, 576, 577, 578, 579, 580, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597, 598, 599, 600, 601, 602, 603, 604, 605, 606, 607, 608, 609, 610, 611, 612, 613, 614, 615, 616, 617, 618, 619, 620, 621, 622, 623, 624, 625, 626, 627, 628, 629, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 641, 642, 643, 644, 645, 646, 647, 648, 649, 650, 651, 652, 653, 654, 655, 656, 657, 658, 659, 660, 661, 662, 663, 664, 665, 666, 667, 668, 669, 670, 671, 672, 673, 674, 675, 676, 677, 678, 679, 680, 681, 682, 683, 684, 685, 686, 687, 688, 689, 690, 691, 692, 693, 694, 695, 696, 697, 698, 699, 700, 701, 702, 703, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744, 745, 746, 747, 748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 775, 776, 777, 778, 779, 780, 781, 782, 783, 784, 785, 786, 787, 788, 789, 790, 791, 792, 793, 794, 795, 796, 797, 798, 799, 800, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 816, 817, 818, 819, 820, 821, 822, 823, 824, 825, 826, 827, 828, 829, 830, 831, 832, 833, 834, 835, 836, 837, 838, 839, 840, 841, 842, 843, 844, 845, 846, 847, 848, 849, 850, 851, 852, 853, 854, 855, 856, 857, 858, 859, 860, 861, 862, 863, 864, 865, 866, 867, 868, 869, 870, 871, 872, 873, 874, 875, 876, 877, 878, 879, 880, 881, 882, 883, 884, 885, 886, 887, 888, 889, 890, 891, 892, 893, 894, 895, 896, 897, 898, 899, 900, 901, 902, 903, 904, 905, 906, 907, 908, 909, 910, 911, 912, 913, 914, 915, 916, 917, 918, 919, 920, 921, 922, 923, 924, 925, 926, 927, 928, 929, 930, 931, 932, 933, 934, 935, 936, 937, 938, 939, 940, 941, 942, 943, 944, 945, 946, 947, 948, 949, 950, 951, 952, 953, 954, 955, 956, 957, 958, 959, 960, 961, 962, 963, 964, 965, 966, 967, 968, 969, 970, 971, 972, 973, 974, 975, 976, 977, 978, 979, 980, 981, 982, 983, 984, 985, 986, 987, 988, 989, 990, 991, 992, 993, 994, 995, 996, 997, 998, 999, 1000.

larger focused spot and a correspondingly lower MTF and cutoff frequency for reading data marks.

Another embodiment of the invention uses a variation of the components shown in FIG. 10 and previously described.

As shown in FIG. 10, an optical transducer 82 performs the functions of both an optical disk recorder and an optical disk reader. When used as an optical disk recorder, the components of the optical transducer 82 perform as previously described with reference to FIG. 10. When used as an optical disk reader, the optical transducer 82 is optically coupled to data marks on the recording layer of optical disk 80. The optical transducer 82 follows a servo track as the optical disk 80 rotates. The data marks cause the optical transducer 82 to produce a data signal as the optical disk 80 rotates. The laser 90 emits a linearly polarized beam of light 92 which is collimated by a collimator lens 94. The light beam 92 passes through a polarization beam splitter 96. The light beam 92 is converted from linear polarization to circular polarization by a quarter wave retardation plate 98. The light beam 92 then passes through an aperture stop 99. The aperture stop 99 is dynamically controlled to be smaller when the optical transducer 82 is used as an optical disk reader and larger when the optical transducer 82 is used as an optical disk recorder. When the diameter of the aperture stop 99 is reduced, the effective numerical aperture of objective lens 100 is reduced. The light beam 92 passes through the objective lens 100 and onto the recording layer of the optical disk 80 containing recorded data marks. The MTF and the cutoff frequency of optical transducer 82 are reduced when the diameter of aperture stop 99 is reduced and a data signal is produced that does not contain unwanted noise produced by a clock reference structure formed on the recording layer of the optical disk 80. A portion of the light beam 92 is reflected by the optical disk 80 and returns through the objective lens 100 and the quarter wave plate 98. Upon passing back through the quarter wave retardation plate 98, the light beam 92 is again linearly polarized. However, the polarization direction of the light beam 92 is rotated 90 degrees relative to its initial orientation. Therefore, the polarization beam splitter 96 reflects substantially all of light beam 92 towards beam splitter 102. The beam 102 splits the beam 92 into a first light beam 104 and a second light beam 106. The first light beam 104 is collected by a first lens 108 onto a first detector 110 which is arranged to produce a focus-error signal. The second light beam 106 is collected by a second lens 112 onto a second detector 114 which is arranged to produce a tracking-error signal used by the tracking positioner. During data detection, detector 114 is also arranged to produce a data signal containing information encoded in data marks on optical disk 80. Detectors 110 and 114 generally include multiple detection areas and produce multiple detection signals as is well known in the art. Many alternative arrangements of the optical components and detectors are possible, including arrangements which combine or eliminate optical components shown in FIG. 10. When adjusted to a higher effective numerical aperture for recording data, the optical transducer 82 provides a smaller focused spot of light and a correspondingly higher MTF and cutoff frequency necessary for recording data marks and producing a clock reference signal. When adjusted to a lower effective numerical aperture, the optical transducer 82 provides a larger focused spot and a correspondingly lower MTF and cutoff frequency necessary for reading data marks.

Although specific embodiments of the invention have been described and illustrated, the invention is not to be limited to the specific forms or arrangements of parts so described and illustrated. The invention is limited only by the claims.

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